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Paleoclimatic variations in the Pliocene of Piedmont (Italy)

Abstract – In the course of a paleontological study on the mid-Pliocenic sediments that are typical of the surroundings of the town of Asti (Piedmont, NW Italy), the author identified macrofaunal successions of paleoclimatic significance.

In particular, marine mollusks associations were found that could be well differentiated chronologically, and comprised alternations of warm-water and temperate to temperate-cold water species. On the basis of these indications the study was extended to the whole Piedmontese paleontological region, with completely similar results from isochronous deposits. The use of macrofaunae to identify paleoclimatic phases was shown to be optimal in these generally coastal sediments (intertidal to littoral).

The microfaunae yielded consistent data although, because of the shallow depth of the sea, planctonic species were generally not abundant.

The body of results was supported by the finding of bivalves and gastropods that were previously unknown or doubtful in the Mediterranean Pliocene, and are of paleoclimatic interest.

Six climatic phases were identified in the sediments, showing alternations of residues of warm sea with much colder waters.

Riassunto – Variazioni Paleoclimatiche nel Pliocene Piemontese.

Durante ricerche paleontologiche effettuate nei sedimenti mesopliocenici tipici dei dintorni della città di Asti (Piemonte, Italia NW) sono state individuate successioni di macrofaune aventi significato paleoclimatico.

In particolare, sono state rinvenute associazioni a Molluschi cronologicamente ben differenziabili e comprendenti, alternativamente, prevalenti ospiti di mare caldo o temperato, fino a temperato-freddo. In base alle indicazioni ottenute l'indagine è stata estesa a tutta la regione paleontologica piemontese, con risultati del tutto analoghi per depositi isocroni. L'utilizzazione delle macrofaune per evidenziare fasi paleoclimatiche si è dimostrata ottimale, in presenza di sedimenti ovunque costieri, da intertidali a litorali.

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Le microfaune hanno fornito dati coerenti pur se, in relazione alla scarsa profondità dei paleofondali, le specie planctoniche sono generalmente non numerose.

L'insieme dei risultati è stato confortato dal ritrovamento di Lamellibranchi e Gasteropodi, precedentemente non noti o conosciuti con dubbio per il Pliocene mediterraneo e interessanti sotto il profilo paleoclimatico.

Nei sedimenti pliocenici considerati sono state riconosciute sei fasi climatiche, con alternanze di residui di mare caldo e decisamente più freddo.

Key words: Pliocene, climatic changes, Molluscks, Piedmont.

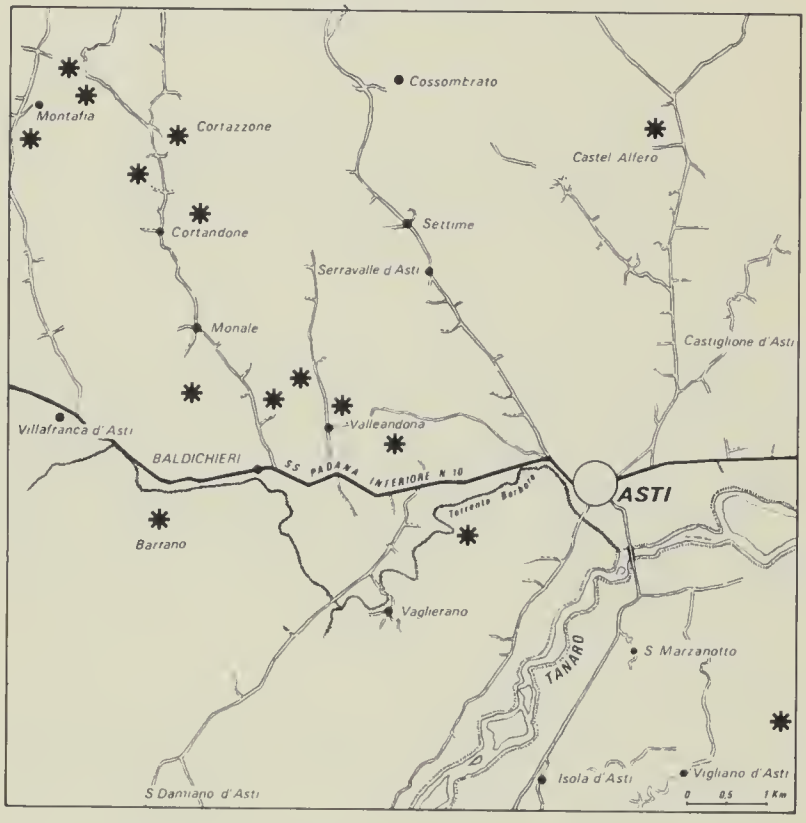

Fig. 1 – Some typical mesopliocenic outcrops near Asti (I.G.M. map-F.69).

Introduction

The stratigraphy and paleoclimate of the Neogene have been the object of increasingly intensive studies in recent times. As regards the Mediterranean basin, increasing amounts of information have been obtained especially from the study of microfaunae (e.g., Alberici et al., 1973; Cita, 1973; Lona, 1962; Marasti and Raffi, 1975; Raffi et al., 1985; Thunell, 1979). As a result, the original concept of a basically homogeneous, warm and subtropical Pliocenic climat has been gradually modified. Recent research, especially on Foraminifera, Radiolaria and nannoplancton, has continued to reveal climatic variations during the Pliocene, including some decidedly cold episodes (e.g., Vergnaud-Grazzini, Bizon, Bertolani-Marchetti, Müller, Dov Por, Riedel et al., Steininger, Rabeder and Rögl in Geological Evolution of the Mediterranean Basin, 1985). As for Piedmont itself, the presence of glaciomarine deposits had already been reported by Bruno (1877) and Stoppani (1880), followed in

more recent times by detailed studies mainly based on the use of microfaunae (Barbieri, Carraro, Medioli and Petrucci. 1974-75).

The set of data obtained for the Mediterranean basin confirmed that paleoclimatic variations occurred in the Pliocene, especially as regards the middle and upper horizons. These deposits are typical in the surroundings of Asti and are well represented in most of the Piedmontese paleontological region. The results of the research on microfaunae and paleoflorae in these sediments helped understand the paleoclimate, but only to a certain extent, because these organisms were scarce in the deposits examined which were completely coastal (e.g., Sampò, Zappi and Caretto, 1968).

In the course of several field investigations in the mid-Pliocenic deposits of the type localities, the author was able to collected and record, from chronologically different sediments, a number of molluscan species that were interesting from the paleoclimatic point of view.

Among these findings were *taxa* of opposite climatic meaning, previously unknown or not well known in the Mediterranean Pliocene, such as: *Venerupis aurea* (Gmelin), *V. geographica* (Chemnitz), *V. pullastra* (Montagu), *V. rhomboides* (Pennant), all typical of temperate seas; *Mya truncata* L., typical of cold waters; *Pteria* (*Pinctada*) *margaritifera studeri* (Mayer) and *Conus pulcher* Lightfoot, typical of subtropical seas (Caretto, 1975a, 1981, 1985a-c, 1986a-b). On the basis of these findings and of other known paleoclimatic indicator organisms, more detailed research was conducted on several isochronous outcrops in Piedmont, covering a large area. Macrofaunae were used in all cases as the basic parameter for the validation and comparison of the data.

The most frequent mollusks, which were particularly abundant at all sites and often well preserved, were considered according to mainly stratigraphic and population criteria. Of particular use in this respect were the three characteristic fossil-bearing levels of these mid-Pliocenic sediments of Piedmont, which extend laterally over large areas without interruption. The study was developed to reach the following main objectives.

- Comprehensive examination of the isochronous macrofaune.
- Verification of the prevalent populations in the associations thus identified.
- Chronological subdivision of the sediments, mainly based on the delimitation of the levels containing thanatocoenoses of mollusks.
- Examination and comparison of the vertical succesions of macrofaunae.
- Paleoclimatic significance of the macrofaunal associations, both vertically and laterally.

Stratigraphic indications

The sediments studied in this investigation are widespread in Piedmont and are found at various localities around the town of Asti, south of it towards the town of Alba, and to the north beyond Turin towards the foothills of the Alps. They were historically attributed to the Astian stage, but are now classified as Middle Pliocene or, according to other interpretations, Upper-Middle Pliocene. The sedimentary complex and its outcrops are shown in Sheets 56, 57 and 69 of the 1 : 100,000 geological map of Italy, which is drawn on the topographical base of the IGM (Military Geographic Institute).

The type sections are parts of sedimentary sequences found in the vicinity of Valleandona near Asti (de Rouville, 1853).

The sediments of the formation under consideration are mainly sandy with medium to medium-fine grain size, yellow to yellowish-grey colour, and an organic residue consisting mainly of hyaline and milky quartz, muscovite, biotite, chlorite, and carbonic substances. In the lower half of the strata the sands sometimes change laterally to rocks of different composition. Thus we have sands with clayey components (e.g., Valle Botto near Valleandona d'Asti), gravelly (e.g., near Vezza d'Alba) and arenaceous (e.g., near Moncalvo d'Asti) (Caretto, 1963, 1966, 1975a). The fossil-bearing outcrops are found especially on the slopes of the rolling hills (negative orogenesis) that are characteristic of the Piedmontese Pliocenic basin. The sediments under consideration have an average thickness of 40-50 m and dips of 4-8°, mainly towards the centre of the basin which is situated near Asti itself. The lithological sequence in the whole paleontological region is essentially as follows, from the bottom upwards:

1) Blue clays of Piacenzian *facies,* forming the base of the basin, varying in thickness up to 150 m, cropping out at the most strongly eroded sites, e.g., west of Asti (Caretto, 1963).

2) The sandy formation considered in this study, overlying the clays without unconformities and characterised by the presence of three fossil-bearing levels displaying a semi-autochtonous thanatocoenosis, extending over the whole basin. The three levels are briefly described below.

a) Lower Level or Complex Level. It usually consists of three sub-zones either in direct contact with one another or separated by thin sandy layers, with a total thickness of about 2 m.
   - Lower Sub-Zone (about 70 cm). Contains several littoral and endobiotic species, among which bivalves are prevalent.
   - Middle Sub-Zone (about 70 cm). Often contains bioclastic fragments. It includes a high number of *taxa,* with bivalves again prevailing.
   - Upper Sub-Zone (about 60 cm). Contains abundant gastropods, bivalves and echinoids, sometimes of large size.

   In this Complex Level, macrofaunae are abundant everywhere. A sequence near Becchi di Castelnuovo don Bosco (Asti) yielded more than 450 different species and subspecies (Caretto, 1981, 1985a-c).

b) Centimetric Level (about 20-30 cm). Located at 7-9 m above the Complex Level, contains e relatively small number of *taxa* and several pectinids.

c) Upper Level, about 2 m thick, a few metres above the Centimetric Level. Contains several gastropod and bivalve *taxa,* with a strong prevalence of *Isognomon maxillatus* and *Pteria* (*P.*) *margaritifera* at the base.

3) Continental sediments of Villafranchian *facies* with grey and red sands, and gravels, which at times were even a few centimetres thichk at base of the formation, are regularly superimposed over the underlying marine formation.

Among the fossil-bearing outcrops the most noteworthy are those near Valleandona d'Asti, Valle Botto and Castelnuovo don Bosco, where the sequences are often complete and easy to correlate.

From the structural point of view, the Piedmontese Pliocenic basin consists of a wide syncline, with a fairly regular shape and without important faults. Subsidence, which is essentially moderate with occasional decreases,

shows a rather slow and gradual retreat of the Pliocenic sea without any outstanding change in water depth, both horizontally and vertically.

Finally, the sediments under consideration are invariably coastal, essentially infralittoral to littoral, with small local variations (e.g., Valle Botto) indicating calmer and deeper water tending to a circalittoral environment.

Paleontological and Paleoclimatic Findings

An examination of the horizontal distribution of the macrofaunae led to the identification of basically homogeneous associations over great distances, with minor changes in composition that were mainly associated with changes in the lithology of the sediments. As a result, no evidence has been found to justify the assumption of different paleoclimatic meanings of isochronous communities.

Vertically, the paleofaunal associations proved easy to differentiate, at times remarkably so.

The basic criterion adopted in the study of the populations was that of verifying the prevalence of the *taxa* among the various paleocommunities recorded.

The associations thus identified, and in particular those associated with colder climates, showed remarkable analogies with present associations with which they could be correlated. Of particular interest were the analogies with recent Mediterranean faunae and, for the Centimetric Level mentioned above, with Atlantic associations, e.g., those of the British coasts. An important aid to our research was also the high number of Pliocenic *taxa* that are still represented in the present time, or that can be compared with similar ones. Additionally, some species appeared to be typical of certain stratigraphic positions or levels.

Essentially, therefore, the faunal variations that were observed by moving upwards in the sequence have yielded valuable elements for the evaluation of the paleoclimatic changes that took place. Thus it became possible to ascertain that alternations of different climatic phases did take place during the deposition of Pliocenic sediments in Piedmont.

On the basis of the chronological subdivisions made possible by the study, the formation under investigation was shown to be charachterised by the presence of the following units (from the bottom upwards): sands above the basal Piacenzian clays, shell-bearing complex level with the three sub-zones mentioned above, sands above this level, shell-bearing centimetric level with pectinids, upper sands up to the *Isognomon* level, shell-bearing *Isognomon* level, upper sands up to the Villafranchian deposits.

The findings on the paleofaunal associations, and the lists of predominant and significant organisms that are amply representative of the whole communities in the individual sub-periods, are presented below. This will serve to outline the substantial modifications that took place in the composition of the predominantly molluscan paleofaunae that succeeded one another in the time interval under investigation, and that are of paleoclimatic importance in relation to similar communities in our time.

It is also noteworthy that several organisms, and more notably *Isognomon* (*Hippochaeta*) *maxillatus* (Lamarck), *Pecten* (*Chlamys*) *latissimus* (Brocchi), *Discors aquitanicus* (Mayer), *Callista* (*C.*) *italica* Defrance, and *Strombus*

coronatus Defrance, disappear more or less abruptly at certain points in the sequence. On the other hand, other species, such as *Myrsopsis pernarum* (Bonelli) and *Murex* (*F.*) *brevicanthos* Sismonda, appear at the top and become typical, for example, only of the *Isognomon* level.

The situation is summarised below. For further information and comparisons of fossil lists with present-time faunae, the reader is referred to Caretto, 1985 a-c, 1986 a-b, and 1987.

A) Sands above the basal Piacenzian clays, up to the shell-bearing complex level (abot 15 m thick).

Warm, temperate-warm phase. The fossils are scattered and more or less uniformly distributed in the yellowish-grey sands. Temperate- to warm-sea species are prevalent. The associations, incidentally, are quite different from those found in the underlying Piacenzian clays, which are not included in this study.

The prevalent representative species are:

Nucula (*N.*) *placentina* Lamarck, *Arca* (*A.*) *noae* L., *Anadara* (*A.*) *darwini* (Mayer), *Glycymeris* (*G.*) *bimaculata* (Poli), *Chlamys flexuosa* (Poli), *Chlamys* (*C.*) *pesfelis* (L.), *Pecten jacobaeus* (L.), *Spondylus* (*S.*) *gaederopus* L., *Lima* (*L.*) *lima* (L.), *Ostrea* (*O.*) *lamellosa* Brocchi, *Megaxinus transversus* (Bronn), *Chama* (*C.*) *gryphoides* L., *Cardites* (*C.*) *antiquatus* (L.), *Acanthocardia* (*A.*) *erinacea* Lamarck, *Laevicardium oblongum* (Gmelin), *Lutraria* (*Eastonia*) *rugosa* (Chemnitz), *Ervilia castanea* (Montagu), *Donax semistriatus* Poli, *Solecurtus strigilatus* (L.), *Pharus legumen* (L.), *Venus* (*V.*) *verrucosa* L., *Callista* (*C.*) *chione* (L.), *Pelecyora gigas* (Lamarck), *Mysia undata* (Pennant), *Panopea glycymeris* (Born), *Thracia pubescens* (Pulteney); *Diodora italica* (Defrance), *Diloma* (*Oxystele*) *patulum* (Brocchi), *Calliostoma* (*Ampullotrochus*) *granulatum* (Born), *Calliostoma corallinus* Gmelin, *Astraea* (*Bolma*) *rugosa* (L.), *Tricolia pullus* (L.), *Turritella* (*Haustator*) *vermicularis* (Brocchi), *Architectonica* (*A.*) *pseudo-perspectiva* (Brocchi), *Lemintina arenaria* (L.), *Cerithium* (*Thericium*) *varicosum* (Brocchi), *Epitonium turtoni* (Turton), *Jantina pallida* Harvey-Thompson, *Xenophora crispa* (Koenig), *Erosaria spurca* (L.), *Zonaria* (*Z.*) *porcellus* (Brocchi), *Naticarius* (*N.*) *stercusmuscarum* (Gmelin), *Naticarius* (*N.*) *epiglottinus* (Lamarck), *Cypraecassis* (*C.*) *pseudocrumena* (d'Orbigny), *Semicassis laevigata* (Defrance), *Cymatium* (*Monoplex*) *distortum* (Brocchi), *Cymatium* (*Lampusia*) *affine* (Deshayes), *Ficus reticulatus* (Lamarck), *Murex brandaris torularius* (Lamarck), *Coralliophila* (*Pseudomurex*) *bracteata* (Brocchi), *Sphaeronassa mutabilis* (L.), *Hinia limata* (Chemnitz), *Fusinus clavatus* (Brocchi), *Cancellaria* (*Bivetiella*) *cancellata* (L.), *Turris* (*T.*) *turricula* (Brocchi), *Conus mercatii* Brocchi, *Hastula* (*H.*) *striata* (Basterot), *Terebra* (*T.*) *acuminata* (Borson), *Turbonilla* (*Pyrgiscus*) *rufa* (Philippi), *Scaphander* (*S.*) *lignarius* (L.), *Bulla* (*B.*) *subampulla* d'Orbigny, *Macularia vermicularis* (Bonelli) (terrestrial).

As was mentioned above, in places where the lithological *facies* changes laterally to sediments with non-sandy components, the faunae show partial changes in composition but not in their overall paleoclimatic and environmental connotations. For example, in the sandy/clayey sediments typical of Valle Botto and its surroundings and almost until Asti, there is a substantial number of gastropod individuals. In this remarkable heteropic *facies*, the following species are particularly well represented among the predominant organisms:

Anadara (*A.*) *diluvii* (Lamarck), *Anadara* (*A.*) *darwini* (Mayer), *Glycymeris* (*G.*) *pilosa* (L.), *Pinna* (*P.*) *nobilis* L., *Chlamys* (*Aequipecten*) *scabrella* (Lamarck), *Pecten* (*Flabellipecten*) *flabelliformis* (Brocchi), *Pecten* (*P.*) *jacobaeus* (L.), *Spondylus* (*S.*) *gaederopus* L., *Ostrea* (*O.*) *edulis* L., *Glans* (*G.*) *intermedia* (Brocchi), *Trachycardium* (*Dallocardia*) *multicostatum* (Brocchi), *Discors aquitanicus* (Mayer), *Ensis ensis* (L.), *Tellina incarnata* L., *Tellina* (*Peronea*) *planata* L., *Gastrana fragilis fragilis* (L.), *Donax semistriatus* Poli, *Azorinus* (*A.*) *chamasolen* (Da Costa), *Callista* (*C.*) *chione* (L.), *Pelecyora* (*P.*) *gigas* (Lamarck); *Diodora italica* (Defrance), *Astraea* (*Bolma*) *rugosa* (L.), *Tornus subcarinatus* (Montagu), *Turritella* (*Haustator*) *vermicularis* (Brocchi), *Lemintina arenaria* (L.), *Bittium reticulatum pliocenicum* (Sacco), *Capulus hungaricus* (L.), *Xenophora crispa* (Koenig), *Aporrhais pespelecani* (L.), *Zonaria* (*Z.*) *porcellus* (Brocchi), *Naticarius* (*N.*) *stercusmuscarum* (Gmelin), *Semicassis laevigata* (Defrance), *Cymatium* (*Lampusia*) *affine* (Deshayes), *Gyrineum* (*Aspa*) *marginatum* (Gmelin), *Malea orbiculata* (Brocchi), *Truncullariopsis truncula conglobata* (Michelotti), *Murex brandaris torularius* (Lamarck), *Buccinulum* (*Euthria*) *corneum* (L.), *Sphaeronassa longoastensis* (Sacco), *Hinia* (*H.*) *musiva* (Brocchi), *Alectrion* (*Desmoulea*) *conglobatus* (Brocchi), *Fasciolaria fimbriata* (Brocchi), *Fusinus rostratus* (Olivi), *Epalxis* (*Bathytoma*) *cataphracta* (Brocchi), *Conus mercatii* Brocchi, *Conus pyrula* Brocchi, *Strioterebrum pliocenicum* Sacco, *Scaphander* (*S.*) *lignarius* (L.), *Bulla* (*B.*) *subampulla* d'Orbigny.

At sites where the sediments become arenaceous or more or less gravelly there is a higher incidence of species that are charachteristic of these environments, but always within the limits of coastal benthofaunae and not of cold water.

Essentially, the macrofaunae found in the paleontological region under investigation always constitute typical warmsea associations, regardless of sediment type.

B) Shell-bearing complex level (about 2 m thick)

B1 - Lower sub-zone (about 70 cm thick). Warm to temperate-warm phase.

Substantial associations of glicimerids are prevalent in these sediments, which display a mainly Astian *facies*. The prevalent species are:

Nucula (*N.*) *placentina* Lamarck, *Arca* (*A.*) *noae* L., *Anadara* (*A.*) *pectinata* (Brocchi), *Glycymeris* (*G.*) *violacescens* (Lamarck), *Chlamys* (*C.*) *varia* (L.), *Chlamys* (*Aequipecten*) *scabrella* (Lamarck), *Pecten* (*P.*) *jacobaeus* (L.), *Spondylus* (*S.*) *gaederopus* L., *Lima* (*L.*) *lians* (Gmelin), *Ostrea* (*O.*) *edulis* L., *Megaxinus* (*M.*) *ellipticus* (Borson), *Chama gryphoides placentina* (Defrance), *Pseudochama* (*P.*) *gryphina* (Lamarck), *Glans* (*G.*) *intermedia* (Brocchi), *Cardites antiquatus pectinatus* (Brocchi), *Acanthocardia* (*A.*) *aculeata* (L.), *Trachycardium* (*Dallocardia*) *multicostatum* (Brocchi), *Laevicardium* (*L.*) *oblongum* (Chemnitz), *Mactra corallina corallina* (L.), *Mactra corallina liguaria* Monterosato, *Spisula* (*S.*) *subtruncata* (Da Costa), *Lutraria* (*Eastonia*) *rugosa* (Chemnitz), *Lutraria* (*L.*) *lutraria* (L.), *Lutraria* (*Psamnophila*) *oblonga* (Chemnitz), *Tellina* (*Arcopagia*) *crassa* (Pennant), *Tellina* (*Arcopagia*) *corbis* (Bronn), *Tellina* (*Moerella*) *donacina* L., *Tellina* (*Peronea*) *planata* L., *Gastrana* (*G.*) *fragilis fragilis* (L.), *Leporimetis papyracea* (Gmelin), *Donax semistriatus* Poli, *Solecurtus scopulus candidus* (Renierj), *Venus* (*Ventricoloidea*) *verrucosa* L., *Venus* (*Ventricoloidea*) *excentrica* Agassiz, *Callista* (*C.*) *chione* (L.), *Callista* (*C.*) *puella* (Philippi), *Callista*

(*C.*) *italica* (Defrance), *Pelecyora* (*P.*) *gigas* (Lamarck), *Dosinia* (*Pectunculus*) *orbicularis* Agassiz; *Diodora italica* (Defrance), *Diloma* (*Oxystele*) *patulum* (Brocchi), *Turritella* (*Haustator*) *vermicularis* (Brocchi), *Architectonica* (*A.*) *monilifera* (Bronn), *Lemintina arenaria* (L.), *Cerithium* (*Thericium*) *varicosum* (Brocchi), *Niso* (*N.*) *eburnea* (Risso), *Capulus hungaricus* (L.), *Crepidula unguiformis* Lamarck, *Xenophora crispa* (Koenig), *Aporrhais pespelecani* (L.), *Erato laevis* (Donovan), *Zonaria* (*Z.*) *flavicula* (Lamarck), *Naticarius* (*N.*) *epiglottinus* (Lamarck), *Cypraecassis* (*C.*) *pseudocrumena* (d'Orbigny), *Cymatium* (*Lampusia*) *affine* (Deshayes), *Gyrineum* (*Aspa*) *marginatum* (Gmelin), *Hexaplex* (*Phillonotus*) *rudis* (Borson), *Mitrella* (*Columbellopsis*) *astensis* (Bellardi), *Sphaeronassa mutabilis* (L.), *Hinia limata* (Chemnitz), *Fusinus clavatus* (Brocchi), *Mitra* (*M.*) *fusiformis* (Brocchi), *Narona* (*Sveltia*) *varicosa* (Brocchi), *Turris* (*T.*) *turricula* (Brocchi), *Conus mercatii* Brocchi, *Conus mediterraneus* «Hwass»-Bruguière, *Hastula* (*H.*) *striata* (Basterot), *Turbonilla* (*Pyrgiscus*) *rufa* (Philippi), *Bulla* (*B.*) *subampulla* d'Orbigny.

In the heteropic *facies* with pelitic components found at Valle Botto and towards Asti, the species already mentioned for this type of sediment continue to predominate and overlie the basal blue clays.

B2 - Middle sub-zone (about 70 cm thick). Medium-temperate phase.

The sands are predominantly medium- to fine-grained, often with pelitic and bioclastic components. The prevalent species are:.

Nucula (*N.*) *nucleus* (L.), *Arca*(*A.*) *noae* L., *Barbatia* (*B.*) *barbata* (L.), *Anadara* (*A.*) *pectinata* (Brocchi), *Glycymeris* (*G.*) *pilosa* (L.), *Mytilus* (*M.*) *scaphoides* Bronn, *Lithophaga lithophaga* (L.), *Modiolus* (*M.*) *barbatus* (L.), (very frequent in lithological clayey-sandy *facies*) *Modiolus* (*M.*) *adriaticus* (Lamarck), *Pinna* (*P.*) *nobilis* L., *Chlamys* (*C.*) *varia* (L.), *Chlamys* (*C.*) *multistriata* (Poli), *Chlamys* (*Flexopecten*) *inaequicostalis* (Lamarck), *Chlamys* (*Flexopecten*) *glabra* (L.), *Anomia* (*A.*) *ephippium* L., *Lima* (*L.*) *hians* (Gmelin), *Neopycnodonte cochlear* (Poli), *Ostrea* (*O.*) *edulis* L., *Alectryonia plicatula* (Gmelin), *Lucinoma borealis* (L.), *Diplodonta* (*D.*) *rotundata* (Montagu), *Bornia* (*B.*) *sebetia* (O. G. Costa), *Epilepton* (*Jagonia*) *reticulatum* (Poli), *Glans* (*G.*) *intermedia* (Brocchi), *Astarte fusca* (Poli), *Acanthocardia* (*A.*) *paucicostata* (Sowerby), *Trachycardium* (*Dallocardia*) *multicostatum* (Brocchi), *Laevicardium* (*L.*) *crassum* (Gmelin), *Spisula* (*S.*) *subtruncata* (Da Costa), *Solen marginatus* (Pennant), *Ensis ensis* (L.), *Tellina* (*Moerella*) *donacina* L., *Tellina* (*Peronea*) *planata* L., *Macoma* (*M.*) *cumana* (O. G. Costa), *Gastrana fragilis fragilis* (L.), *Donax semistriatus* Poli, *Gari* (*Psammobia*) *fervensis* (Gmelin), *Abra* (*Syndosmya*) *alba* (Wood), *Azorinus* (*A.*) *chamasolen* (Da Costa), *Venus* (*Ventricoloidea*) *casina* L., *Pitar* (*P.*) *rudis rudis* (Poli), *Callista* (*C.*) *puella* (Philippi), *Pelecyora* (*P.*) *brocchi* (Deshayes), *Dosinia lupinus* (L.), *Venerupis aurea aurea* (Gmelin), *Venerupis geographica* (Chemnitz), *Venerupis rhomboides* (Pennant), *Chamelea* (*C.*) *gallina gallina* (L.), *Clausinella fasciata* (Da Costa), *Timoclea* (*T.*) *ovata* (Pennant), *Corbula revoluta* (Brocchi), *Hiatella* (*H.*) *arctica* L., *Panopea* (*P.*) *glycymeris* (Born), *Thracia pubescens* (Pulteney); *Diodora gibberula* (Lamarck), *Jujubinus striatus* (L.), *Jujubinus smaragdinus* (Monterosato), *Diloma* (*Oxistele*) *patulum* (Brocchi), *Calliostoma zizyphinum* (L.), *Clanculus corallinus* (Gmelin), *Circulus striatus* (Philippi), *Tricolia tenuis* (Michaud), *Littorina neritoides* (L.), *Apicularia sulzeriana* (Risso), *Tornus subcarinatus* (Montagu), *Architectonica* (*A.*) *simplex* (Bronn), *Petaloconchus intortus* (Lamarck), *Bittium reticulatum*

pliocenicum (Sacco), *Cerithium* (*Thericium*) *varicosum* (Brocchi), *Niso* (*N.*) *eburnea* (Risso), *Calyptraea chinensis* (L.), *Aporrhais pespelecani* (L.), *Erosaria spurca* (L.), *Neverita josephinia* Risso, *Lunatia catena* (Da Costa), *Naticarius* (*N.*) *dillwyni* (Payreaudeau), *Cymatium* (*Monoplex*) *partenopaeum* (Von Salis), *Buccinulum* (*Euthria*) *corneum* (L.) (mostly in clayey-sandy *facies*), *Sphaeronassa mutabilis* (L.), *Hinia* (*Hima*) *musiva* (Brocchi), *Cancellaria* (*Bivetiella*) *cancellata* (L.), *Conus mediterraneus* «Hwass»-Bruguière, *Hastula* (*H.*) *striata* (Basterot), *Turbonilla* (*Pyrgiscus*) *rufa* (Philippi), *Bulla* (*B.*) *subampulla* d'Orbigny.

The climatic control of the predominant species in the middle sub-zone always points to a paleoenvironment with moderate temperatures in temperate waters, and in any case colder than those of the other subdivisions of the complex level.

B3 - Upper sub-zone (about 60 cm thick). Warm subtropical phase.

In these sandy layers the faunal association is further modified, at times with mascroscopically evident features such as large-size species, up to the large pectinids and stromboids. Several typical warm-sea organisms are usually contained in these predominantly sandy and essentially Astian-*facies* deposits. The following species are noteworthy or more frequent:

Nucula (*N.*) *placentina* (Lamarck), Arca (*A.*) *noae* L., *Anadara* (*A.*) *pectinata* (Brocchi), *Glycymeris* (*G.*) *bimaculata* (Poli), *Glycymeris* (*G.*) *violacescens* (Lamarck) (at times extraordinarily abundant), *Pinna* (*Atrina*) *pectinata* (L.), *Pecten* (*Hinnites*) *crispus* (Brocchi), *Pecten* (*Chlamys*) *latissimus* (Brocchi), *Pecten* (*Flabellipecten*) *flabelliformis* (Brocchi), *Pecten* (*P.*) *jacobaeus* (L.), *Spondylus* (*S.*) *gaederopus* L., *Spondylus* (*S.*) *crassicosta* Lamarck, *Lima* (*L.*) *lima* (L.), *Ostrea* (*O.*) *edulis* L., *Ostrea* (*O.*) *lamellosa* Brocchi, *Codakia leonina* (Basterot), *Pseudochama* (*P.*) *gryphina* (Lamarck), *Glans* (*Centrocardita*) *rudista* (Lamarck), *Cardites antiquatus pectinatus* (Brocchi), *Laevicardium* (*L.*) *oblongum* (Chemnitz), *Discors aquitanicus* (Mayer), *Lutraria* (*Eastonia*) *rugosa* (Helbling), *Tellina* (*Arcopagia*) *crassa* (Pennant), *Tellina* (*Arcopagia*) *sedgwicii* (Michelotti), *Tellina* (*Peronea*) *planata* L., *Leporimetis papyracea* (Gmelin), *Solecurtus scopulus candidus* (Renierj), *Pharus legumen* (L.), *Venus* (*Ventricoloidea*) *verrucosa* L., *Venus* (*Ventricoloidea*) *excentrica* Agassiz, *Callista* (*C.*) *chione* (L.), *Dosinia* (*Pectunculus*) *exoleta* (L.), *Dosinia* (*Pectunculus*) *orbicularis* Agassiz; *Diodora italica* (Defrance), *Astraea rugosa* (L.), *Turritella* (*Haustator*) *vermicularis* (Brocchi), *Lemintina arenaria* (L.), *Crepidula unguiformis* Lamarck, *Xenophora crispa* (Koenig), *Strombus coronatus* Defrance, *Erato laevis* (Donovan), *Zonaria* (*Z.*) *pyrum* (Gmelin), *Zonaria* (*Z.*) *porcellus* (Brocchi), *Sinum haliotoideum* (L.), *Naticarius* (*N.*) *stercusmuscarum* (Gmelin), *Cassidaria echinophora* (L.), *Cypraecassis* (*C.*) *pseudocrumena* (d'Orbigny), *Semicassis laevigata* (Defrance), *Cymatium* (*Monoplex*) *distortum* (Brocchi), *Cymatium* (*Lampusia*) *affine* (Deshayes), *Gyrineum* (*Aspa*) *marginatum* (Gmelin), *Malea orbiculata* (Brocchi), *Ficus reticulatus* (Lamarck), *Trunculariopsis truncula conglobata* (Michelotti), *Murex brandaris torularius* (Lamarck), *Coralliophila* (*Pseudomurex*) *bracteata* (Brocchi), *Sphaeronassa longoastensis* (Sacco), *Alectrion* (*Desmoulea*) *conglobatus* (Brocchi), *Fasciolaria fimbriata* (Brocchi), *Fusinus clavatus* (Brocchi), *Mitra* (*M.*) *fusiformis* (Brocchi), *Narona* (*Sveltia*) *varicosa* (Brocchi), *Turris* (*T.*) *turricula* (Brocchi), *Epalxis* (*Bathytoma*) *cataphracta* (Brocchi), *Conus mercatii* Brocchi,

Conus aldrovandi Brocchi, *Conus pulcher* Lightfoot, *Conus pelagicus* Brocchi, *Hastula* (*H.*) *striata* (Basterot), *Strioterebrum* (*S.*) *reticulare* (Pecchioli), *Subula* (*S.*) *fuscata* (Brocchi), *Terebra* (*T.*) *acuminata* Borson, *Scaphander* (*S.*) *lignarius* (L.).

C) Sands above the complex level (about 15 m thick).

Gradual cooling of the climate to temperate or temperate-cold. These sands display a gradual reduction of warm-sea faunae. The following species are prevalent:

Nucula (*N.*) *nucleus* (L.), *Barbatia* (*B.*) *barbata* (L.), *Anadara* (*A.*) *diluvii* (Lamarck), *Glycymeris* (*G.*) *pilosa* (L.), *Pinna* (*P.*) *nobilis* L., *Pinna* (*Atrina*) *pectinata* (L.), *Chlamys* (*Aequipecten*) *scabrella* (Lamarck), *Chlamys* (*Manupecten*) *pesfelis* (L.), *Pecten* (*Flabellipecten*) *flabelliformis* (Brocchi), *Pecten* (*P.*) *jacobaeus* (L.), *Anomia* (*A.*) *ephippium* L., *Lima* (*L.*) *lima* (L.), *Ostrea* (*O.*) *edulis* L., *Lucinoma borealis* (L.), *Diplodonta* (*D.*) *rotundata* (Montagu), *Glans* (*G.*) *intermedia* (Brocchi), *Cardium* (*Bucardium*) *hians* Brocchi, *Acanthocardia echinata* (L.), *Laevicardium* (*L.*) *oblongum* (Chemnitz), *Mactra corallina lignaria* Monterosato, *Ensis ensis* (L.), *Tellina* (*Moerella*) *donacina* L., *Tellina* (*Oudardia*) *compressa* Brocchi, *Macoma* (*M.*) *cumana* (O. G. Costa), *Gari* (*Psammobia*) *fervensis* (Gmelin), *Azorinus* (*A.*) *chamasolen* (Da Costa), *Corbula* (*Varicorbula*) *gibba* (Olivi), *Hiatella* (*H.*) *rugosa* (Pennant), *Nototeredo norvagicus* (Spengler); *Diodora gibberula* (Lamarck), *Gibbula magus* (L.), *Calliostoma zizyphinum* (L.), *Calliostoma conulum* (L.), *Tornus subcarinatus* (Montagu), *Turritella* (*haustator*) *vermicularis* (Brocchi), *Mathilda quadricarinata* (Brocchi), *Petaloconchus intortus* (Lamarck), *Bivonia triquetra* (Bivona), *Niso* (*N.*) *terebellum* (Chemnitz), *Niso* (*N.*)*eburnea* Risso, *Calyptraea chinensis* (L.), *Crepidula unguiformis* Lamarck, *Aporrhais pespelecani* (L.), *Neverita josephinia* Risso, *Naticarius stercusmuscarum* (Gmelin), *Naticarius* (*N.*) *dillwyni* (Payraudeau), *Malea orbiculata* (Brocchi), *Ficus reticulatus* (Lamarck), *Sphaeronassa mutabilis* (L.), *Hinia* (*H.*) *reticulata* (L.), *Fusinus rostratus* (Olivi), *Fusinus clavatus* (Brocchi), *Cancellaria* (*Bivetiella*) *concellata* (L.), *Narona* (*Sveltia*) *varicosa* (Brocchi), *Strioterebrum* (*S.*) *reticulare* (Pecchioli), *Eulimella* (*E.*) *scillae* (Scacchi), *Scaphander* (*S.*) *lignarius* (L.).

D) Centimetric level with prevalent pectinids (about 30 cm thick). Temperate to temperate-cold phase.

Temperate to temperate-cold water species are decidedly abundant in these sands, where they generally form similar associations to those found in the present time, for example, along the British coastline. The following species are widespread:

Nucula (*N.*) *nucleus* (L.), *Nuculana* (*Lembulus*) *pella* (L.), *Barbatia* (*Soldania*) *mytiloides* (Brocchi), *Anadara* (*A.*) *pectinata* (Brocchi), *Glycymeris* (*G.*) *glycymeris* (L.), *Glycymeris* (*G.*) *pilosa* (L.), *Modiolus* (*M.*) *adriaticus* (Lamarck), *Modiolus* (*M.*) *barbatus* (L.), *Pinna* (*P.*) *nobilis* L., *Palliolum* (*Delectopecten*) *simile* (Laskey), *Palliolum* (*Lyssochlamys*) *excisum* (Bronn), *Chlamys* (*C.*) *varia* (L.), *Chlamys* (*Aequipecten*) *opercularis* (L.), *Pecten* (*Flabellipecten*) *alessii* (Philippi), *Pecten* (*Flabellipecten*) *nigromagnus* (Sacco), *Pecten* (*P.*) *maximus* (L.), *Anomia* (*A.*) *ephippium* L., *Lima* (*L.*) *hians* (Gmelin), *Neopycnodonte* (*P.*) *cochlear* (Poli), *Ostrea* (*O.*) *edulis* L., *Astarte* (*A.*) *sulcata* (Da Costa), *Lucina* (*L.*) *orbicularis* Deshayes, *Diplodonta* (*D.*) *rotundata* (Montagu), *Cardium* (*Bucardium*) *hians* Brocchi, *Acanthocardia* (*A.*) *echinata* (L.), *Acanthocardia* (*A.*)

paucicostata (Sowerby), *Cerastoderma* (*C.*) *edule* (L.), *Lutraria* (*L.*) *lutraria* (L.), *Tellina* (*Moerella*) *pulchella* Lamarck, *Tellina* (*Moerella*) *donacina* L., *Tellina* (*Oudardia*) *compressa* Brocchi, *Tellina* (*T.*) *serrata* Renierj, *Macoma* (*Psammacoma*) *elliptica* (Brocchi), *Scrobicularia plana* (Da Costa), *Abra* (*Syndosmya*) *alba* (Wood), *Solecurtus scopulus candidus* (Renierj), *Azorinus* (*A.*) *chamasolen* (Da Costa), *Glossus humans* (L.), (= *Isocardia cor* (L.)), *Venus* (*Ventricoloidea*) *casina* L., *Clausinella fasciata* (Da Costa) *Venerupis* (*V.*) *aurea* (Gmelin), *Chamelea gallina striatula* (Da Costa), *Mya truncata* L., *Corbula* (*Varicorbula*) *gibba* (Olivi), *Hiatella* (*H.*) *arctica* (L.), *Hiatella* (*H.*) *rugosa* (Pennant); *Diodora gibberula* (Lamarck), *Gibbula magus* (L.), *Calliostoma* (*C.*) *zizyphinum* (L.), *Circulus striatus* (Philippi), *Tricolia pullus* (L.), *Mathilda quadricarinata* (Brocchi), *Petaloconchus intortus* (Lamarck), *Bivonia triquetra* (Bivona), *Calyptraea* (*C.*) *chinensis* (L.), *Neverita josephinia* Risso, *Lunatia* (*L.*), *catena* (Da Costa), *Naticarius* (*N.*) *stercusmuscarum* (Gmelin) (= *N.* (*N.*) *millepunctatus* (Lamarck), *Naticarius* (*N.*) *dillwyni* (Payraudeau), *Naticarius* (*N.*) *pseudoepiglottinus* (Sismonda), *Sphaeronassa* (*S.*) *mutabilis* (L.), *Hinia* (*H.*) *reticulata* (L.), *Hinia* (*H.*) *limata* (Chemnitz), *Hinia* (*H.*) *incrassata* (Ström), *Fusinus rostratus* (Olivi), *Narona* (*Sveltia*) *varicosa* (Brocchi).

E) Sands above the centimetric level (about 1-2 m thick). Transition phase to warm climate.

The paleofaunae in these yellow sands exhibit rapid changes. While the temperate-climate species disappear, large ostreids are seen in the upper layers, and extensive oligoassociations of Brachiopods (genus *Terebratula*) are often found near the contact with the overlying *Isognomon* level. Spondilids and pectinids (genus *Hinnites*) are also present.

F) *Isognomon* level (about 2 m thick). Warm subtropical phase.

The macrofaunae are markedly different from those of the underlying level. Large pearl oysters of the species *Pteria* (*Pinctada*) *margaritifera studeri* (Mayer), a clear indicator of subtropical waters, are often in evidence near the base.

Isognomon individuals are extremely abundant. They are associated with bivalves and gastropods, all attributable to warm-water coastal environments. The following species are prevalent in association with the pearl oysters:

Arca (*A.*) *noae* L., *Barbatia* (*Soldania*) *mytiloides* (Brocchi), *Barbatia* (*Cucullearca*) *candida* (Chemnitz), *Glycymeris* (*G.*) *bimaculata* (Poli), *Isognomon* (*Hippochaeta*) *maxillatus* (Lamarck), *Pecten* (*Flabellipecten*) *flabelliformis* (Brocchi), *Spondylus* (*S.*) *crassicosta* Lamarck, *Ostrea* (*O.*) *lamellosa* Brocchi, *Glans* (*G.*) *intermedia* (Brocchi), *Cardites antiquatus pectinatus* (Brocchi), *Discors aquitanicus* (Mayer), *Lutraria* (L.) *lutraria* (L.), *Lutraria* (*Psammophila*) *oblonga* (Chemnitz), *Tellina* (*Peronea*) *planata* L., *Venus* (*Ventricoliodea*) *verrucosa* L., *Circomphalus foliaceolamellosus* (Dillwin), *Callista* (*C.*) *chione* (L.), *Myrsopsis pernarum* Bonelli; *Diodora italica* (Defrance), *Astraea rugosa* (L.), *Turritella* (*Haustator*) *vermicularis* (Brocchi), *Lemintina arenaria* (L.), *Zonaria* (*Z.*) *pyrum* (Gmelin), *Cypraecassis* (*C.*) *Pseudocrumena* (d'Orbigny), *Cymatium* (*Lampusia*) *affine* (Deshaves), *Murex brandaris torularius* (Lamarck), *Murex* (*Favartia*) *brevicanthos* Sismonda, *Mitra* (*M.*) *fusiformis* (Brocchi), *Turris turricula* (Brocchi), *Conus mercatii* Brocchi, *Subula* (*S.*) *fuscata* (Brocchi).

G) Sands above the *Isognomon* level (about 7 m thick). Phase tending to a temperate climate.

The *Isognomon* suddenly disappear and the paleofaunal associations display a prevalence of species not exclusively found in warm water, similar to those found at the present time in Mediterranean areas. The following species are noteworthy:

Nucula (*N.*) *placentina* Lamarck, *Arca noae* L., *Arca tetragona* Poli, *Barbatia* (*Soldania*) *mytiloides* (Brocchi), *Anadara* (*A.*) *pectinata* (Brocchi), *Glycymeris* (*G.*) *pilosa* (L.), *lithophaga Lithophaga* (L.), *Pinna* (*P.*) *nobilis* L., *Chlamys* (*C.*) *multistriata* (Poli), *Chlamys* (*Manupecten*) *pesfelis* (L.), *Pecten* (*P.*) *jacobaeus* (L.), *Spondylus* (*S.*) *gaederopus* L., *Lima lima* (L.), *Ostrea* (*O.*) *Edulis* L., *Alectryonia plicatula* (Gmelin), *Megaxinus ellipticus* (Borson), *Lucinoma borealis* (L.), *Diplodonta* (*D.*) *rotundata* (Montagu), *Lepton* (*L.*), *nitidum* (Turton), *Astarte sulcata* (Da Costa), *Acanthocardia* (*A.*) *echinata* (L.), *Trachicardium* (*Dallocardia*) *multicostatum* (Brocchi), *Laevicardium* (*L.*) *oblongum* (Chemnitz), *Mactra corallina* (L.), *Solen marginatus* (Pennant), *Ensis ensis* (L.), *Tellina* (*Arcopagia*) *crassa* (Pennant), *Tellina* (*Peronea*) *planata* L., *Tellina serrata* Renierj, *Donax venustus* Poli, *Gari* (*Psammobia*) *fervensis* (Gmelin), *Solecurtus strigilatus* (L.), *Circomphalus foliaceolaınellosus* (Dillwin), *Pitar* (*P.*) *rudis* (Poli), *Callista* (*C.*) *puella* (Philippi), *Paphia* (*Callistotapes*) *vetula* (Basterot), *Thracia pubescens* (Pulteney), *Juiubinus striatus* (L.), *Diloma* (*Oxistele*) *patulum* (Brocchi), *Calliostoma cingulatum* (Brocchi), *Circulus striatus* (Philippi), *Turritella* (*Haustator*) *vermicularis* (Brocchi), *Architectonica* (*A.*) *pseudo-perspectiva* (Brocchi), *Petaloconchus intortus* (Lamarck), *Cerithium* (*Thericium*) *varicosum* (Brocchi), *Crepidula unguiformis* Lamarck, *Aporrhais pespelecani* (L.), *Erato laevis* (Donovan), *Zonaria* (*Z.*) *porcellus* (Brocchi), *Naticarius* (*N.*) *dillwyni* (Payraudeau), *Cymatium* (*Monoplex*) *parthenopaeum* (Von Salis), *Gyrineum* (*Aspa*) *marginatum* (Gmelin), *Hexaplex* (*Phillonotus*) *rudis* (Borson), *Fasciolaria fimbriata* (Brocchi), *Narona* (*Sveltia*) *varicosa* (Brocchi), *Raphitoma* (*R.*) *harpula* (Brocchi), *Terebra* (*T.*) *acuminata* Borson.

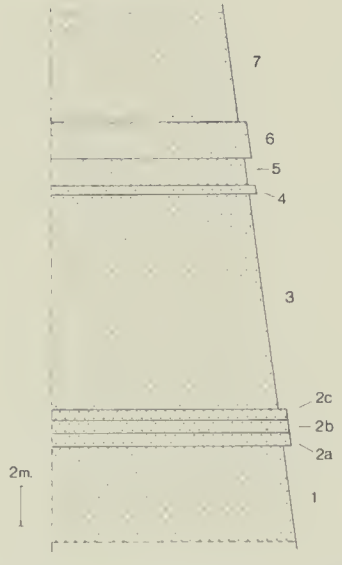

Fig. 2 – Schematic section of the mid-Pliocenic deposits near Asti (north-west Piedmont, Italy). 1 - Sands above the basal Piacenzian clays. 2 - Shell-bearing complex level (p. 167). 2a - Lower sub-zone. 2b - Middle sub-zone. 2c - Upper sub-zone. 3 - Sands above the complex level. 4 - Centimetric level with pectinids (p. 170). 5 - Sands above the centimetric level. 6 - Shell-bearing *Isognomon* level with pearl oysters. 7 - Sands above the *Isognomon* level.

At the top, the Astian sands change more or less abruptly to continental sands and gravels of Villafranchian *facies*.

Remarks on Microfaunae and Paleoflorae

As was mentioned above, microfaunae, and especially the often more significant planctonic species, are generally scarce in these coastal sediments, most of which were certainly disturbed at the time of deposition. At certain sites where deposits of finer grain size indicate deeper water, but still in a littoral environment, there is a higher frequency of Foraminifera. The lack of indications arises from insufficient numbers of both species and individuals. At any rate, the studies conducted on these mid-Pliocenic sands have invariably led to this conclusion.

In particular, a study by Sampò, Zappi and Caretto, 1968, has yielded exhaustive information on these microfaunae, with small vertical sampling intervals. No substantial differences were found in the whole paleontological region investigated.

The results, however, clearly indicated the presence of *Eponides frigidus granulatus* Di Napoli, a tipically cold-water species, above the complex level overlying the basal clays. This is in close agreement with the composition of the macrofaunae in these deposits, which indicate a gradual but substantial cooling of the Pliocenic climate. The other results of the study are also in general agreement with the indications provided by the macrofaunae.

Additionally, during a study on mid-Pliocenic deposits in Emilia (a region of northern Italy), F. Barbieri examined new specimens from the typical sequences near Valleandona and Valle Botto, and obtained similar results to those previously discussed (Barbieri, 1967 and Caretto, 1986).

From the indications of these microfaunae (Foraminifera and Nannoplancton) the following deductions have been made:

a) The composition and areal distribution of the microfaunae confirm the Pliocenic age of the sediments.

b) The abundance of *Elphidium crispum* (L.), in the lower levels and its marked decrease nearly up to the *Isognomon* level could be significant from the paleoclimatic viewpoint and not only as regards *facies* (warm water at the beginning and then cooler, followed by a return to higher temperatures).

The decrease in the frequency of this foraminiferal could also be related to the appearance of *Eponides frigidus granulatus* Di Napoli (see above), as reported for Valleandona and its surroundings.

c) *Florilus boueanus* (d'Orb.), which is also abundant in sediments of similar age at Castell'Arquato in Emilia, is an interesting species and warrants further studies to establish its possible paleoclimatic significance as an indicator of colder waters.

Conclusions

From the chronological point of view it is possible to confirm that the paleofaunal associations are not repeated as a whole and that different organisms become rarer, disappear or appear at certain points of the sequences over an extensive area.

As regards the uniformly coastal environments of the paleontological region under investigation, all the macrofaunae can be shown to have colonised mobile sea bottoms with a marked prevalence of sandy deposits.

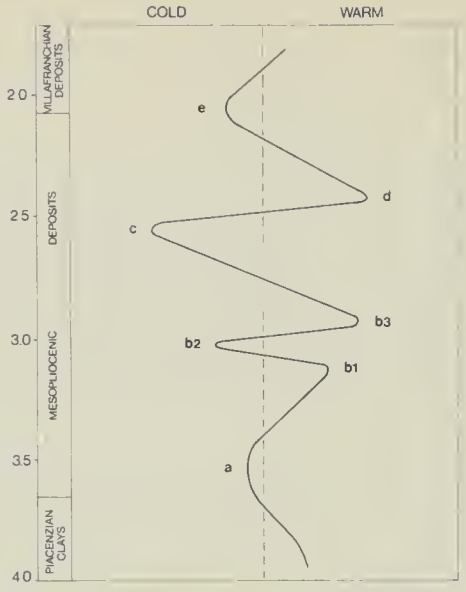

Fig. 3 — a - Sands above the basal Piacenzian clays (p. 166). b - Shell-bearing complex level (p. 167). b1 - Lower sub-zone (p. 167). b2 - Middle sub-zone (p. 168). b3 - Upper sub-zone (p. 169). c - Centimetric level with pectinids (p. 170). d - Shell-bearing *Isognomon* level (p. 171). e - Sands above the *Isognomon* level (p. 171).

The chronostratigraphic examination of the macrofaunae also confirmed that warm and cold paleoclimatic phases alternated during the Middle Pliocene in the whole Piedmontese basin. On the basis of the reported results the paleoclimatic phases can be summarised as follows, from the bottom upwards (Fig. 2):

1) Sands above the Piacenzian clays: warm to temperate-warm sea;
2) Shell-bearing complex level:
a) Lower sub-zone: temperate-warm climate;
b) Middle sub-zone: temperate climate;
c) Upper sub-zone: warm subtropical sea;

3) Sands above the complex level: gradual decrease of the average temperature down to temperate-cold;

4) Shell-bearing centimetric level: temperate to temperate-cold climate;

5) Upper sands, up to the *Isognomon* level: rapid change to a warmer climate;

6) *Isognomon* level with pearl oysters at the base: warm subtropical climate;

7) Overlying sands, up to the continental Villafranchian deposits: tendency to a cooler, temperate-warm climate.

As regards the intensity and duration of the paleoclimatic phases identified by the study, it can be stated that they were relatively short, with the exception of that associated with the upper sediments of the complex level which was longer and more intense.

The situation is shown schematically in Fig. 3.

The results obtained from the study of macrofaunae agree on the whole with those obtained in other isochronous regions, mainly from recent studies on microfaunae. Noteworthy among these studies are those contained in Geological Evolution of the Mediterranean Basin (1985). In particular, the pattern obtained from the present study is in close agreement with that deve-

loped by C. Müller (1985, p. 477, Fig. 22.2), quite independently and for another Pliocenic sedimentary basin, using calcareous nannoplancton.

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